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Journal of Mechanical Engineering

An International Journal

Volume 12 No. 1 June 2015 ISSN 1823-5514

JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Journal of Mechanical Engineering (ISSN 1823-5514) is published by the Faculty of Mechanical Engineering (FKM) and UiTM Press, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

Journal of Mechanical Engineering

An International Journal

Volume 12 No. 1 **June 2015** **ISSN 1823-5514**

The Effect of Skin Orientation on Biomechanical Properties

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ABSTRACT

Skin technology has become a world interest recently and further investigations could improve the current application of skin and leather. Aligning to this, a biomechanical analysis of animal skin is carried out, where the sheepskins are investigated thoroughly using uniaxial tensile tests. The main aim of this study is to compare the biomechanical properties of sheepskin in means of hair effect and orientation layout between horizontal and vertical orientation. The testing specimens are taken from the fresh slaughtered Boer sheepskin and they are prepared into four categories; horizontal (unshaved), horizontal (shaved), vertical (unshaved) and vertical (shaved) according to ASTM International Standard test method for tensile strength of leather (D2209). As a result, the characterisation techniques show that the Ogden's coefficient, μ and Ogden's exponent, α, are 0.369 (MPa) and 7.604 respectively for horizontal (unshaved). However, μ and α for horizontal (shaved) are 0.512 (MPa) and 8.930. In contrast, the value of μ and α for vertical (unshaved) are 0.444 (MPa) and 9.928 and for vertical (shaved) are 0.539 (MPa) and 10.617. This study has contributed to the knowledge of biomechanics especially biomechanical properties of sheepskin. This could be useful for future investigation and analysis of soft-tissues, hyperelastic modeling and animal dermatology.

Keywords: *Biomechanical, skin properties, sheepskin, hair effect, hyperelastic*

ISSN 1823-5514

Introduction

Utilisation of animal skin has started in the early century. Humans have used animal skin as clothing, food and also as musical instruments. Knowing the benefits of animal skin, a large number of researches has been developed with different purposes and needs of investigation. This paper also explains the scientific finding that has been investigated on animal skin and to be specific sheepskin on biomechanical properties. The main aim of this study is to compare the biomechanical properties of sheepskin in means of hair effect and orientation layout between horizontal and vertical orientation. The significance of this research leads towards skin technology either for computer modelling or medical surgery. With this research, it could assist engineers or scientists to explore the skin behaviour without in-vivo procedure. Study of skin is it human or animal has been developed by many researchers. As an example Zeng et al. used 6 adult dogs over 20 kg to determine the biomechanical properties of skin in vitro for different expansion methods [1]. Besides, Uzes et al. examined the mechanical properties of pigskin by using two (2) small pigs [2]. Apart from that, Derakhshanfar and his team used 30 male rats from Sprague-Dawley family, weighing 180-200 g in their study to see the effect of the Peganum Harmala extract on experimental skin wound healing in rats: pathological and biomechanical findings [3]. Another researcher investigated the bovine skin parameter under uniaxial tension for fresh sample [4]. It shows that all of the researchers have done studies on biomechanical properties of skin on mammal's skin since there is a similarity to the human skin structure. On the other hand, human skin biomechanical properties were studied using in-vivo technique of indention [5] by Abellan et al.

Skins behave and react in different ways as compared to rubber. As we know, rubber can be categorised to have elastic behaviour. Even though some schools of thought said skins have similarity with rubber behaviour but many scholars of biomaterial agreed that skin behaves as anistropic, viscoleastic and hyperelastic [6-9]. As an example those researchers used theory from Ogden, Mooney-Rivlin, Neo-Hookean and many more. All the theories assumed the skin is non-linear materials. In this study, the Ogden model was used in order to determine the material parameter values of μ and α for all categories of specimens. This model makes it possible to determine a large number of optimal sets of parameters [10]. Therefore, the Ogden model is recommended for the analysis of large deformation in rubber-like material. Besides, this model can be declared as the best model since it can be applied to numerical analysis in general working deformation [11].

Currently, computational analysis and simulation was integrated with respective theories of material to reduce the time consumed in developing the numerical analysis. For example, Ansys software has readied the required theory in their system. By having the parameter values, it is ready to analyse any design and shape. A few researchers have successfully analysed the human skin using FEA-Ansys software [12-13]. Furthermore, computational and simulation approach were used to analysed human Cerebral Aneurysm using their mechanical properties as an advances procedure [14]. Since this paper focuses on experiment-numerical integrated works only, therefore further investigation via simulation analysis using computational software suggested as future study.

Methodology

This section provides details of quantification procedure of sheepskin biomechanical properties. Figure 1 shows the methodology outline.

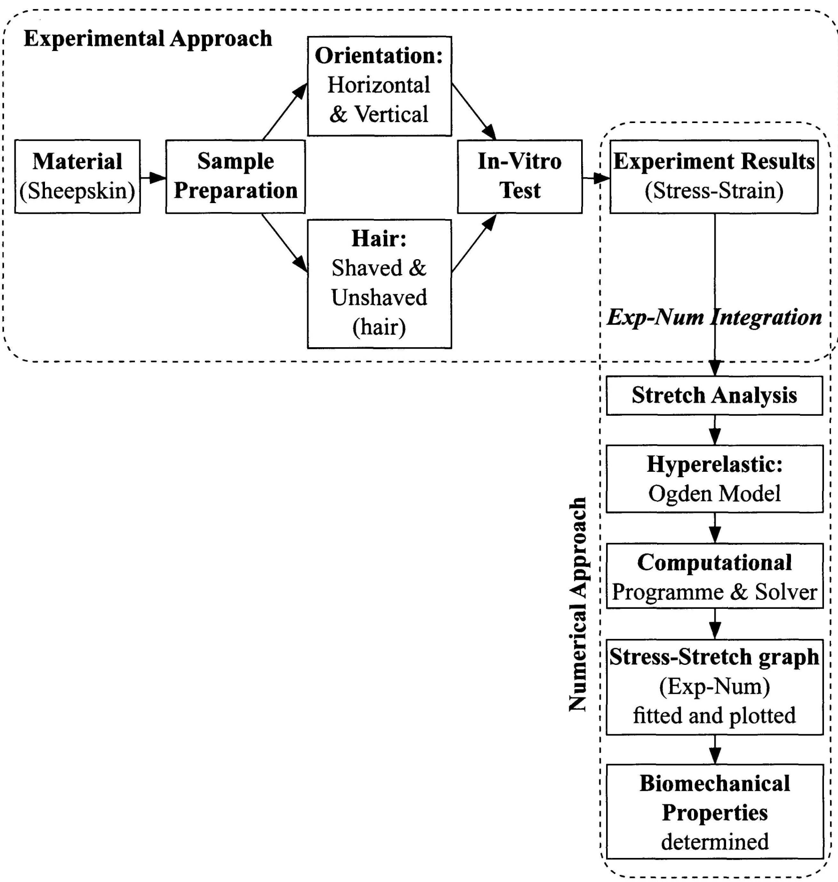

Figure 1: Research flow of Experiment-Numerical Integration on sheepskin

Material gathering

The main material as sample of sheepskin was obtained from a slaughterhouse near the university. Fresh slaughtered skin was obtained from a matured male Boer sheep aged 18 months and weighing approximately 40 kg. A confirmation was made to ensure that the male sheep had no sign of skin infection or limbs. All skin was straight excised with surgical scalpel to ensure the freshness of specimen for in-vitro procedure.

Specimen preparation

The skin was prepared into dumbbell shape as in ASTM International Standard. The first step should be done in specimen preparation process is preparing the template according to a standard size followed. For this process, the template was prepared using vinyl cardboard and the schematic of template as in Figure 2. Next, the skin was excised according to the outer line of the template prepared. The test specimen was prepared on two main categories that had been pre-determined which are horizontal and vertical of skin with spine direction as in Figure 3 and Table 1. Each of these will be divided into two groups between hair and shaved fur. And now it will be noted as shown in Table 1. For each categories or groups, eight (8) specimens were prepared to ensure the homogeneous results were obtained. In the testing performed, altogether twenty eight (28) specimens were prepared for the testing. Figure 2 until 5 illustrates the skin orientation and specimens prepared.

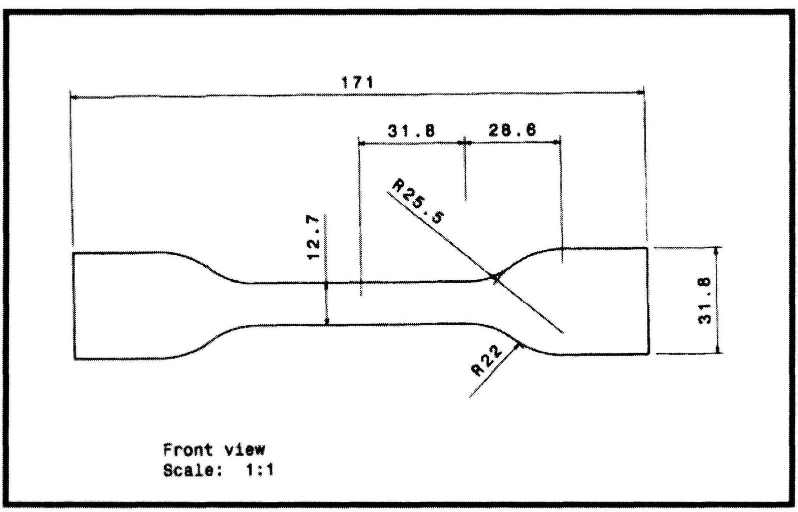

Figure 2: Standard measurement of dumbbell shape according to ASTM international standard (unit-mm)

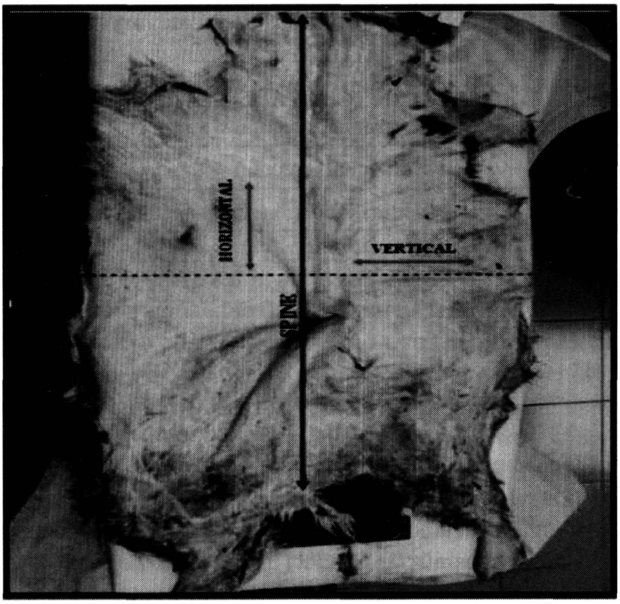

Figure 3: Direction of horizontal and vertical cutting on the skin

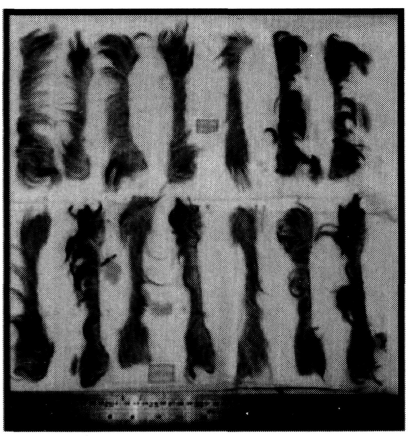

Figure 4: Unshaved specimens

Figure 5: Shaved specimens

Table 1: Notation for each category

Notation	Description
HH	Horizontal direction with hair/fur
HS	Horizontal direction without hair (shaved)
VH	Vertical direction with hair/fur
VS	Vertical direction without hair (shaved)

In-Vitro test

The main testing for this study is uniaxial tensile test. The Universal Tensile Machine model INSTRON 3382 located in strength of material laboratory, Faculty of Mechanical Engineering UiTM. For the testing; as mentioned in previous section, it was followed by the ASTM International Standard test method for strength of leather (D2209) for the whole process and procedures. The machine has the capability to conduct uniaxial tensile test. To avoid slippage during testing operation, special knurled jig and fixture were used to clamp the specimens as shown in Figure 6. With this jig and fixture the whole testing process ran smoothly without any mistake or slippage during the extension or tensile operation.

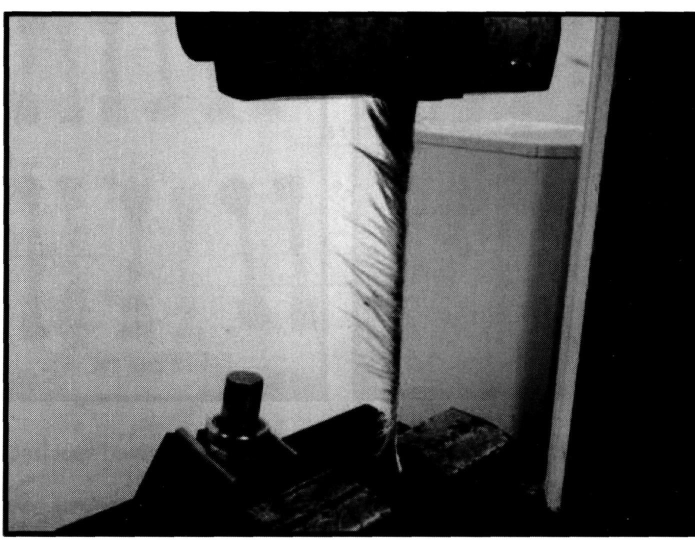

Figure 6: Experimental set-up

Data analysis

As an analysis of biomechanical characterisation, the combination of experiment raw data and hyperelastic material model were required. By having strain values in experiment procedure, the stretch of material can be calculated from a simple equation of strain that associate with stretch:

$$\varepsilon = \lambda - 1 \tag{1}$$

Where, ε and λ are strain and stretch respectively.

Furthermore, with this stretch parameter, the simplified hyperelastic (Ogden) then can be integrated to determine the Ogden parameter as shown in Equation 2 that was derived and simplified from strain energy function of Ogden constitutive modeling. Since we have numbers of stretch values of different stress level with one equation, then it could be computed simultaneously to get the specific Ogden coefficient, μ and Ogden exponent, α in which the results could help future investigation with finite element analysis model. The selected hyperelastic model is the suitable model for skin analysis as recommended [11].

$$\sigma_s = \frac{\mu}{\lambda}(\lambda^{\alpha} - \lambda^{-\alpha/2}) \tag{2}$$

where, σ_s = Predicted Stress
μ = Ogden coefficient (MPa)
α = Ogden exponent

For numerical integration analysis, the simplified equation (2) will be integrated with computational solver in MS Excel 2000 for the optimum value of Ogden parameter.

Results and Discussion

In this section the two categories of specimens that have been divided between horizontal and vertical with two subcategories between unshaved and shaved for the stress-stretch value will be discussed. From the graphs of stress against stretch plotted for each specimen's category, it can be seen that they produce the good stress-stretch curve trend of hyperelastic. Furthermore, the graphs (Figure 7 to 10) showing small dispersion at the maximum stress. For unshaved case on both orientations, whether horizontal or vertical, it almost dropped to the same line, which means the test performed resulted in a homogeneous reading. These are clearly shown in Figure 7 and 8 where these figure come from unshaved specimen for either horizontal or vertical orientation.

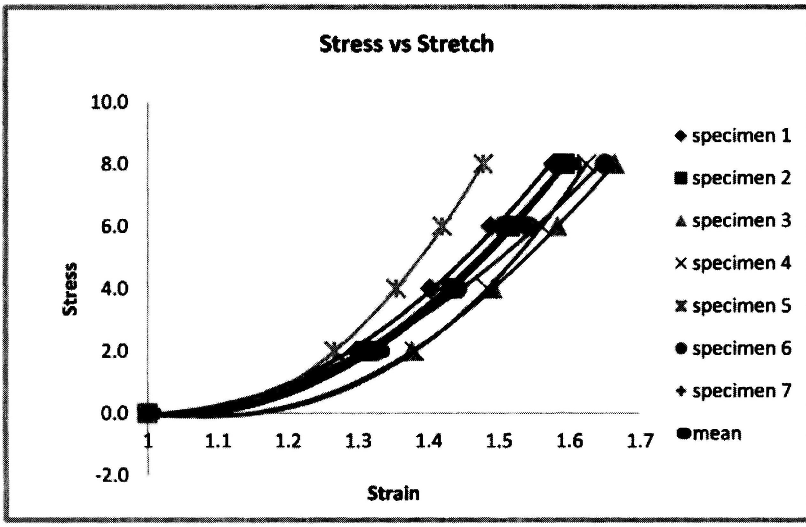

Figure 7: Graph of stress against stretch for HH specimens

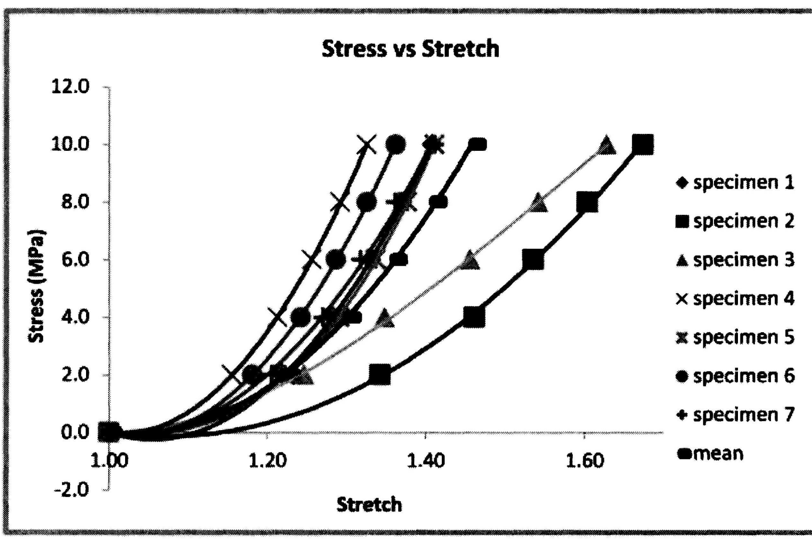

Figure 8: Graph of stress against stretch for HS specimens

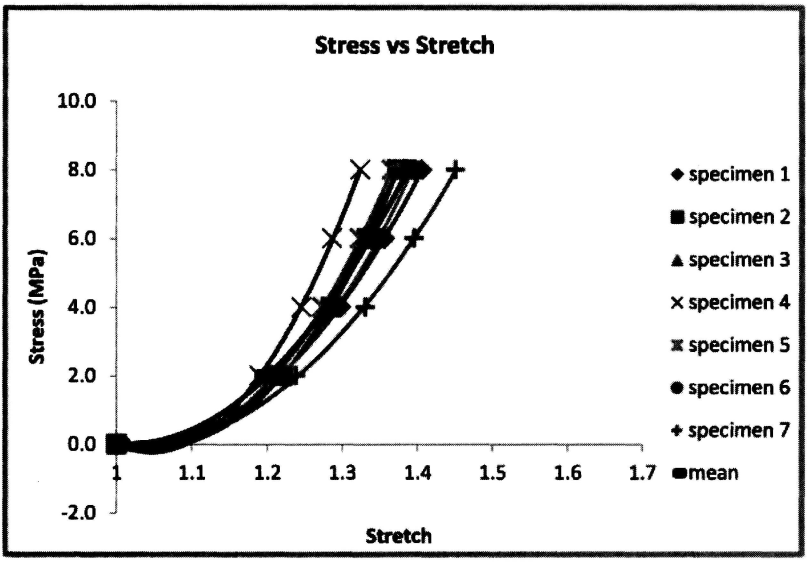

Figure 9: Graph of stress against stretch for VH specimens

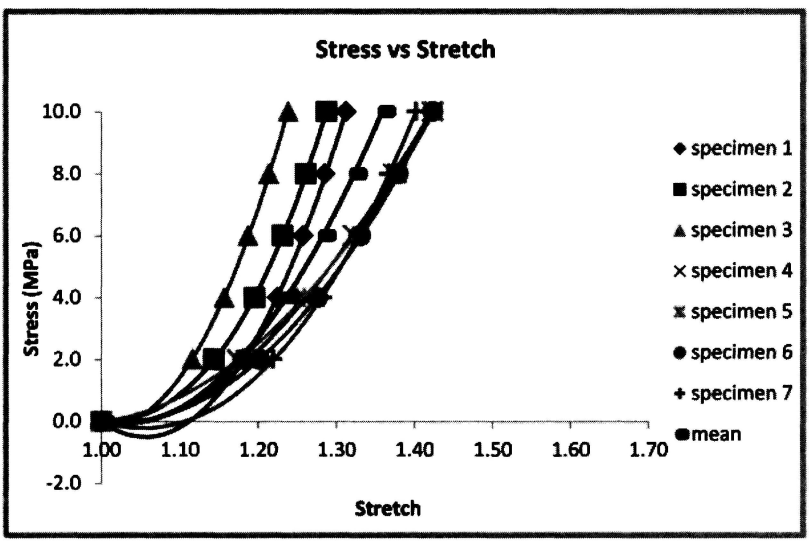

Figure 10: Graph of stress against stretch for VS specimens

Based on Table 2, at maximum stress level, the range stretch value of minimum and maximum were 0.186, 0.347, 0.127 and 0.187 for HH, HS, VH and VS respectively. With small amount of range between min-max values indicates that acceptable testing results obtained. Further statistical analysis was presented in Table 4.

Table 2: Stretch value of HH specimen

Effect	Stress, MPa	Stretch							
		S 1	S 2	S 3	S 4	S 5	S 6	S 7	Mean
HH	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	2	1.298	1.310	1.377	1.380	1.267	1.325	1.321	1.325
	4	1.402	1.434	1.492	1.484	1.354	1.441	1.425	1.433
	6	1.489	1.516	1.583	1.561	1.420	1.543	1.500	1.516
	8	1.578	1.593	1.665	1.625	1.479	1.651	1.598	1.598
HS	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	2	1.220	1.342	1.246	1.155	1.222	1.181	1.206	1.225
	4	1.284	1.462	1.348	1.213	1.291	1.243	1.271	1.302
	6	1.331	1.536	1.456	1.257	1.337	1.287	1.318	1.360
	8	1.370	1.604	1.542	1.292	1.377	1.326	1.362	1.410
	10	1.408	1.673	1.628	1.326	1.411	1.362	1.411	1.460
VH	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	2	1.215	1.219	1.209	1.190	1.209	1.217	1.238	1.190
	4	1.298	1.285	1.278	1.246	1.274	1.293	1.331	1.286
	6	1.356	1.333	1.328	1.286	1.324	1.348	1.396	1.339
	8	1.406	1.374	1.373	1.324	1.366	1.393	1.451	1.384
VS	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	2	1.180	1.143	1.116	1.188	1.173	1.201	1.219	1.174
	4	1.225	1.195	1.157	1.261	1.259	1.276	1.283	1.237
	6	1.257	1.231	1.187	1.321	1.322	1.331	1.327	1.282
	8	1.286	1.261	1.214	1.373	1.377	1.379	1.367	1.322
	10	1.312	1.287	1.238	1.422	1.425	1.423	1.402	1.358

Based on the Table 3, the values of μ and α can be compared. As a result, the material parameters of α for vertical shaved and vertical unshaved category are higher compared to the horizontal shaved and unshaved category. The values of α for vertical unshaved and vertical shaved are 9.928 and 10.617 respectively. However the values of α for horizontal unshaved and horizontal shaved are 7.604 and 8.930. For the material parameter of μ, the same pattern of data was also obtained as the material parameter of α where the values of μ for vertical shaved and vertical unshaved category are greater than horizontal unshaved and horizontal shaved which are 0.444 and 0.539. In contrast, the value of μ for horizontal unshaved and horizontal shaved are 0.369 and 0.512. From this findings value, it also can be analysed that the material parameter value of μ and α for shaved category including horizontal and vertical are larger than the unshaved category for horizontal and vertical. According to the previous research skin on bovine [4], the Ogden parameters for μ and α were 0.4 and 4.6 respectively with unshaved condition. However, for this sheepskin, it is not much different and the values are in the same range. As verification proposes, it is acceptable for the finding to be contributed as collection of data for animal skin properties.

Table 3: Material parameter values of μ and α for each category

Category	μ (MPa)	α
Horizontal (Hair)	0.369	7.604
Horizontal (Shaved)	0.512	8.930
Vertical (Hair)	0.444	9.928
Vertical (Shaved)	0.539	10.617

From the results obtained, it demonstrates that the skin in horizontal direction has higher mean stretch value compared to the skin in the vertical category. By viewing the unshaved and shaved category, the results show that most of the specimens in unshaved category for both horizontal and vertical have greater strain and stretch value than the horizontal (shaved) and vertical (shaved) category as in Table 6. This point of view enables the conclusion that the fur on the skin also gives the effect on its biomechanical properties. Hence, unshaved skin can be declared as skin that is stronger compared to the shaved skin. Nevertheless, the material parameter values of μ and α for the horizontal category are lower than the material parameter values of μ and α for the vertical category. On top of that, the result shows that the values of μ and α for unshaved category are smaller than shaved category. So, it also can be concluded that when the skin has high stretch value, it will have the small value of material parameters (μ and α) and vice versa. For this study it can be established that the skin in horizontal (unshaved) category is the strongest followed by horizontal (shaved), vertical (unshaved) and vertical (shaved) categories. In addition, Figure 11 and Table 4 illustrate the standard deviation of stretch value dispersion. Clearly with error bar as in Figure 10 indicates the small results dispersion in experimental works where shows a good testing performed and homogeneous results. With variance less than 0.05 or (<5%) prove that the results is acceptable in this analysis.

Table 4: Statistical results

Orientation	Stretch (Mean)	Std. Dev	Variance
HH	1.598	0.061	0.004
HS	1.460	0.135	0.018
VH	1.384	0.039	0.002
VS	1.358	0.078	0.006

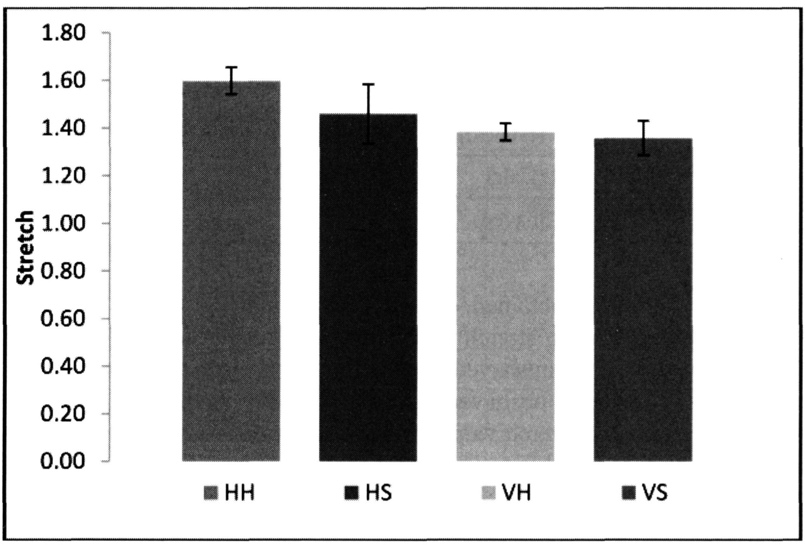

Figure 11: Average stretch at maximum stress

The main reasons of differences in results between horizontal and vertical direction is due to the anistropic behavior of skin. This behavior explained that different direction of skin or orientation cause different material properties. Ni Annaidh et al. mentioned that human skin follow the orientation of Langer line that was propose by Langer. Therefore obviosly the animal skin or sheepskin mechanical properties dependent to the orientation. Oliveira et al. also highlights in their study that direction effect on mechanical properties [15]. On the other hand, differences in hair (unshaved) and shaved results due to different location of sample taken from the animal skin. Suppose that the hair/fur does not affect result because of the skin structure. Skin structure consist of multilayer of soft-tissues start from stratum on the outer layer, followed by epidermis, dermis and subcutaneous as the inner layer. The hairfolical developed from the subcutaneous layer and grow up until outer layer of stratum layer as fur/hair. By knowing this structure, its indirectly explained the shaved and unshaved does not affect the mechanical properties of skin. With different results obtained in the analysis, obviously due other reasons and might cause by different location of the skin.

To end this study, we provide a validation figure of our finding compared to other previous research that associate with soft-tissue and skin. This (Table 5) shows that the current results biomechanical properties of sheepskin that has been quantified in-line with others research.

Table 5: Research on soft-tissues and skin adapting Hyperelastic Ogden Model

μ	α	Author	Test Sample	Test	Ref
10 kPa	110	Mahmud et al. (2010)	Human skin (ventral forearm)	DIC	[7]
0.369-0.539 (MPa)	8.930-10.617	Current study	Sheepskin	uniaxial	
0.4 MPa	4.6	Adull Manan (2013)	Bovine skin	Uniaxial	[4]
0.4-2.8 (MPa)	3	Shergold (2006)	Silicone B453	Compression	[18]
0.4-7.5 (MPa)	12	Shergold (2006)	Silicone 8800	Compression	[18]
1.399-2.309 (MPa)	9.421-9.640	Cooney et al. (2015)	Linea alba-pig	Uniaxial & biaxial	[16]
2.1-8 (MPa)	2.5	Shergold (2006)	Pig skin	Compression	[18]
4.860 (MPa)	25.00	Pancheri (2014)	Goat skin	Uniaxial & biaxial	[17]

Conclusion

The main objective of this research has been successfully fulfilled, where the biomechanical properties of sheepskin between horizontal and vertical orientation were quantified. By having Table 6, the important Ogden coefficient and exponent material parameter for sheepskin determined and contribute the knowledge of biomechanical properties of sheepskin for future skin research.

Acknowledgement

This work was funded by the Ministry of Higher Education of Malaysia and Universiti Teknologi MARA (UiTM) under National Grant Scheme no ERGS/1/2012/TK01/UiTM/02/1 and (UiTM File. No. 600-RMI/ERGS 5/3 (16/2012)). The authors would like to acknowledge the dedicated technicians and student-Noor Azzira Sulaiman for their assistance at the Strength of Materials Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi MARA.

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JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Aims & Scope

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Contributions are invited from various disciplines that are allied to mechanical engineering. The contributions should be based on original research works. All papers submitted to JMechE are subjected to a reviewing process through a worldwide network of specialized and competent referees. To be considered for publication, each paper should have at least two positive referee's assessments.

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Equations should be typed and all symbols should be explained within the manuscript. An equation should be proceeded and followed by one blank line, and should be referred to, in the text, in the form Equation (1).

$$y = A + Bx + Cx^2 \tag{1}$$

Last point: the references. In the text, the references should be a number within square brackets, e.g. [3], or [4]–[6] or [2, 3]. The references should be listed in numerical order at the end of the paper.

Journal references should include all the surnames of authors and their initials, year of publication in parenthesis, full paper title within quotes, full or abbreviated title of the journal, volume number, issue number and pages.

Examples below show the format for references including books and proceedings

Examples of references:

[1] M. K. Ghosh and A. Nagraj, "Turbulence flow in bearings," Proceedings of the Institution of Mechanical Engineers 218 (1), 61-4 (2004).
[2] H. Coelho and L. M. Pereira, "Automated reasoning in geometry theorem proving with Prolog," J. Automated Reasoning 2 (3), 329-390 (1986).
[3] P. N. Rao, Manufacturing Technology Foundry, Forming and Welding, 2nd ed. (McGraw Hill, Singapore, 2000), pp. 53-68.
[4] Hutchinson, F. David and M. Ahmed, U.S. Patent No. 6,912, 127 (28 June 2005).